College of Engineering
Electrical Engineering Department

EE497

Antennas for Internet of Things (IOT Antennas)

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PROJECT ABSTRACT

Project objectives:

- Study the concepts of IOT antennas.
- Design compact IOT antennas: low cost, compact and wide band antennas.
- Develop the IOT antennas designed based on the manufacturing capacity in KSU.

Project requirements:

- Basic knowledge of CST Microwave studio program.
- Basic knowledge of antenna.

Expected results of project:

- Students will study internet of things and IOT antennas.
- Study the frequency spectrum used for IOT antennas also simulation packages to design antennas.
- . Study the different IOT antenna designing technologies by literature review.
- Design efficient antennas suitable for IOT applications.

ACKNOWLEDGEMENT

Knowledge of electromagnetic theory and basic knowledge of antennas

EE213: Engineering Electromagnetics I

EE214: Engineering Electromagnetics II

EE423: Antennas and Wave propagation

And With advice and guidance of

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1 INTRODUCTION

1.1 Problem Formulation

1.1.1 Problem Statement:

The growing market of the Internet of Things (IOT) calls for various types of electronic components and communication technologies for a wide spectrum of applications including smart cities and vehicles, home automation, telemedicine, and industrial applications. Obviously, the successful functionality of these applications is dependent on a reliable wireless component. Among the multitude of attention and discussion that surrounds the Internet of Things (IOT), the subject of antenna performance is not always properly considered. Sometimes, this lack of attention is driven by certain interpretations of IOT, based on which of several low cost devices are close to each other with no need for powerful transceivers. Even in those scenarios, antenna performance remains very important because of issues such as noise, fading and the need for efficiency. Therefore, antennas are an essential element for the IOT.

1.1.2 Problem Formulation:

Internet of Things means an infinitude of connected devices and small sensors, integrated in a bigger network with a permanent access to the user. One of its major application is in the Smart home concept, allowing more convenience, efficiency (at various aspects) and safety. With more and more devices, it is nowadays mandatory for these devices to be small, low power and at the same time more capable and efficient. In this project, the students will study the importance of small and efficient antenna for IOT applications and design antennas suitable for IOT devices, by developing high bandwidth antennas according to the growing needs of wireless networks. This antenna has reduced dimensions, ideal to be integrated in most of IOT sensors.

1.2 About IOT

1.2.1 What is IOT?

The Internet of Things (IOT) describes the network of physical objects—"things"—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet. These devices range from ordinary household objects to sophisticated industrial tools.

1.2.2 Why is IOT so important?

Over the past few years, IOT has become one of the most important technologies of the 21st century.Now that we can connect everyday objects—kitchen appliances, cars, thermostats, baby monitors—to the internet via embedded devices, seamless communication is possible between people, processes, and things.

By means of low-cost computing, the cloud, big data, analytics, and mobile technologies, physical things can share and collect data with minimal human intervention. In this hyperactive connected world, digital systems can record, monitor, and adjust each interaction between connected things. The physical world meets the digital world—and they cooperate.

1.2.3 IOT applications:

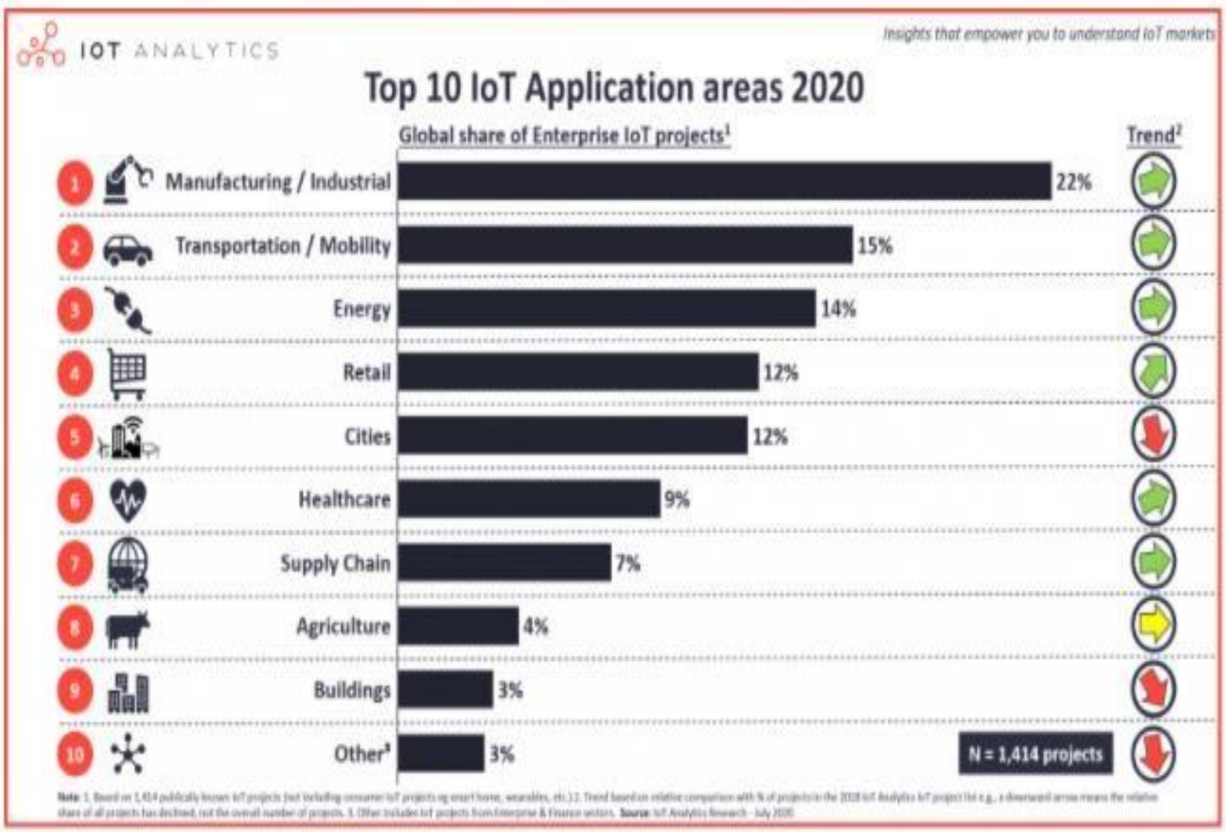


Figure 1: Top 10 IOT applications in 2020.

Figure.1 shows that the 2020 analysis of the top IOT application areas shows that of the 1,414 public enterprise IOT projects identified, Manufacturing / Industrial settings are most common (22%), followed by Transportation / Mobility (15%) and Energy IOT projects (14%). [1]

The 2020 analysis is based on 1,414 actual IOT projects that were explored as part of IOT Analytics' research tracking IOT platforms and the underlying data is included in the 2020 list of 620 IOT platforms. The fact that more than 1,000 publicly announced IOT projects now make use of an IOT platform highlights the importance and pervasiveness of IOT platforms in bringing IOT solutions to market.

1.3 Project Specifications

The feed line calculation in CPW design is depicted in Figure 2, whereas the detailed geometry of the proposed antenna is shown in Figure 3. The antenna is fabricated on an FR4 substrate with relative permittivity of 4.4 having a standard thickness of 1.6 mm. The length, width, and the wavelength of the main rectangular patch is calculated and gradually modified by calculating the resonant frequencies for first and second resonance bands using the following expressions for coplanar waveguide design. [8]

$$L4 = \frac{c}{4 f_{\min} \sqrt{\varepsilon_{r.\mathrm{eff}}}}$$

$$L2 = \frac{c}{4 f_{\max} \sqrt{\varepsilon_{r.\mathrm{eff}}}}$$

$$f1 = \frac{c}{4 Y_g \sqrt{\varepsilon_{r.\mathrm{eff}}}}$$

$$\varepsilon_{r.\mathrm{eff}} = \frac{\varepsilon_r + 1}{2},$$

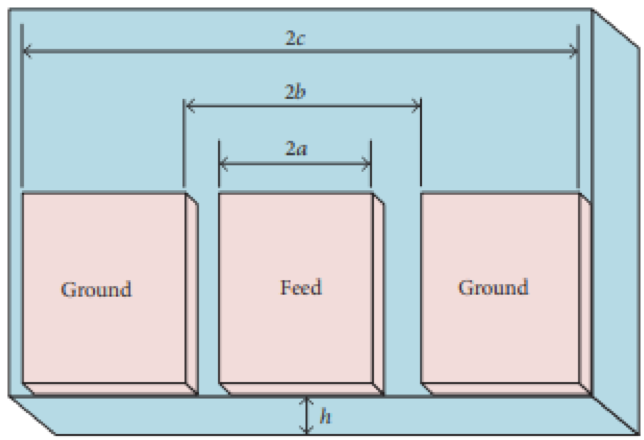


Figure 2: Feed line calculation in CPW design.

Where "c" is the speed of light, $\varepsilon_{r.eff}$ is the efective relative permittivity of substrate which is equal to 2.7, and "Y_g" is the guided wavelength which depends on the length of upper and lower strips for both bands.

2 BACKGROUND

2.1 History and Information:

In radio engineering, an antenna or aerial is the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver [2]. In transmission, a radio transmitter supplies an electric current to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves (radio waves). In reception, an antenna intercepts some of the power of a radio wave in order to produce an electric current at its terminals that is applied to a receiver to be amplified. Antennas are essential components of all radio equipment.

An antenna is an array of conductors (elements), electrically connected to the receiver or transmitter. Antennas can be designed to transmit and receive radio waves in all horizontal directions equally (omnidirectional antennas), or preferentially in a particular direction (directional, or high-gain, or “beam” antennas). An antenna may include components not connected to the transmitter, parabolic reflectors, horns, or parasitic elements, which serve to direct the radio waves into a beam or other desired radiation pattern.

The first experiments that involved the coupling of electricity and magnetism and showed a definitive relationship was that done by Faraday somewhere around the 1830s. He slid a magnetic around the coils of a wire attached to a galvanometer. In moving the magnet, he was in effect creating a time-varying magnetic field, which as a result (from Maxwell's Equations), must have had a time-varying electric field. The coil acted as a loop antenna and received the electromagnetic radiation, which was received (detected) by the galvanometer - the work of an antenna. Interestingly, the concept of electromagnetic waves had not even been thought up at this point [2].

Heinrich Hertz developed a wireless communication system in which he forced an electrical spark to occur in the gap of a dipole antenna. He used a loop antenna as a receiver, and observed a similar disturbance. This was 1886 [3].

The first antennas were built in 1888 by German physicist Heinrich Hertz in his pioneering experiments to prove the existence of waves predicted by the electromagnetic theory of James Clerk Maxwell. Hertz placed dipole antennas at the focal point of parabolic reflectors for both transmitting and receiving .Starting in 1895, Guglielmo Marconi began development of antennas practical for long-distance, wireless telegraphy, for which he received a Nobel Prize [4].
By 1901, Marconi was sending information across the atlantic. For a transmit antenna, he used several vertical wires attached to the ground. Across the Atlantic Ocean, the receive antenna was a 200 meter wire held up by a kite [1.1].

In 1926, Japanese inventor Shintaro Uda, with the help of his colleague, Hidetsugu Yagi, developed the Yagi-Uda antenna. Modern versions of this antenna are used on high frequency (HF), very high frequency (VHF), and ultra high frequency (UHF) bands due to its characteristically high gain.

Horn antennas, 1939. Interesting, the early antenna literature discussed waveguides as "hollow metal pipes".
Antenna Arrays, 1940s
Parabolic Reflectors, late 1940s, early 1950s.
Patch Antennas, 1970s [1.1].

2.2 Concept Synthesis:

Conventional coplanar waveguide (CPW) consists of a single conducting track printed onto a dielectric substrate, together with a pair of return conductors, one to either side of the track. All three conductors are on the same side of the substrate, and hence are coplanar. The return conductors are separated from the central track by a small gap, which has an unvarying width along the length of the line. Away from the central conductor, the return conductors usually extend to an indefinite but large distance, so that each is notionally a semi-infinite plane.

Coplanar waveguide (CPW) was invented in 1969 by Cheng P. Wen, primarily as a means by which non-reciprocal components such as gyrators and isolators could be incorporated in planar transmission line circuits [5].

The electromagnetic wave carried by a coplanar waveguide exists partly in the dielectric substrate, and partly in the air above it. In general, the dielectric constant of the substrate will be different (and greater) than that of the air, so that the wave is travelling in an inhomogeneous medium. In consequence, CPW will not support a true TEM wave; at non-zero frequencies, both the E and H fields will have longitudinal components (a hybrid mode). However, these longitudinal components are usually small and the mode is better described as quasi-TEM. [6]

2.3 Design Parameters :

(CPW) suitable for Ultra Wide band (UWB) communication. It consists of two ground planes etched on the both side of the radiator. A ground plane having the slot structure. i.e. partial ground. By using a circle shaped radiator with rectangular cut provides much impedance bandwidth. This antenna has a better return loss less than -10 dB for operating frequency of 7 GHz. The S11 and VSWR are simulated using HFSS.[7]

Geometry of the proposed antenna is shown in Figure 2.3. With The parameters value are shown in table 2.[8]

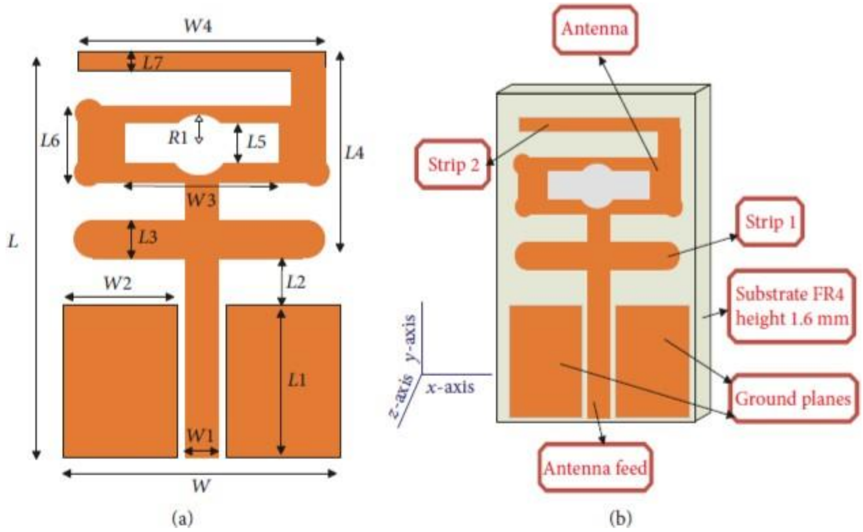


Figure 2.3: Geometry of the proposed antenna: (a) parametric details and (b) major components of proposed antenna.

Parameter	L	W	L1	W1	L2	W2	L3	W3
Value/mm	35	25	14.8	2	3.7	10.5	2	13
Parameter	L4	W4	L5	L6	R1	L7	h	g
Value/mm	14.3	17	3	7	2.5	0.5	1.6	1

Table 2.1: Proposed CPW antenna design parameters values.

Parametric study is performed on the antenna by investigating the effect of various geometrical parameters on the frequency characteristics. The antenna is fabricated and measured. It has better return loss response and stable gain over the entire UWB band. The antenna has stable radiation pattern and good impedance matching over entire ultra-wide bandwidth of 3–10.6 GHz. The results show that there is good agreement between measured and simulated results. Various features such as compactness, simple configuration and low fabrication cost make the antenna suitable for UWB and wireless local area network systems.[9]

3 THEORY

3.1 Material

We used FR-4 material for the substrate , and for other components we used copper because it is used as electrical and thermal conductivity metal. It doesn't react with water and it act very slowly with air. copper is recyclable without any loss of quality.

flame retardant (FR-4):

FR4 is the most common material grade that comprises fabricated circuit boards. 'FR' indicates the material is flame retardant and the '4' indicates woven glass reinforced epoxy resin. The properties of FR4 may vary slightly depending on the manufacturer; however, it generally has favorable strength and water resistance attributes that support its widespread usage as an insulator for many electrical applications. It serves the same purpose in PCBs, namely to isolate adjacent copper planes and provide overall bending and flexural strength for the structure. FR4 is a good general purpose material for PCB fabrication. [11]

For describe design methodology for a circular microstrip antenna. The generic antenna layout highlighting the main design parameters and dimensions is shown in Figure 3.1.1, where R is the radius of the circular patch, FR4 is the radius where the desired input impedance is calculated, L is the length and W is the width of the feed line.

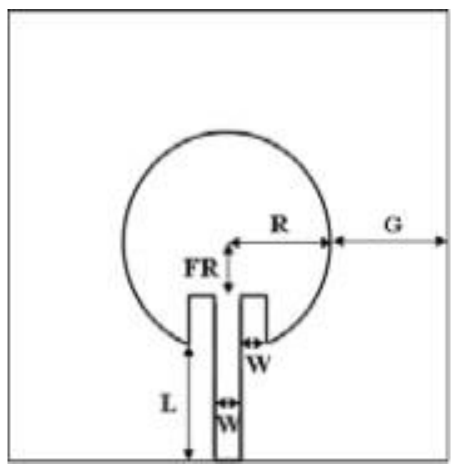


Figure 3.1.1: Side-fed circular microstrip patch antenna.

The feed line is a quarter-wave transformer to match the input impedance of the patch to 50 ohm. The distance G between the radiating element edge and the ground edge is lamb/4. The commercially available FR-4 substrate was used in the antenna fabrication. It has specifications as shown in TABLE 3.1.2. These parameters are used in the design procedure for determining the radius and input impedance of the circular patch antenna. Equation (1) was used to calculate the radius, R of the antenna. [13]

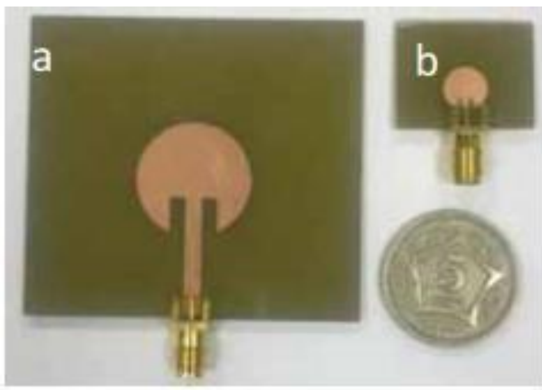
$$R = F * \left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{-1/2} \quad (1)$$

Where $F = \frac{8.791x10^9}{f_r\sqrt{\varepsilon_r}}$, f_r is the resonance frequency in Hz, $\mathcal{E}_r$ is the substrate dielectric constant (relative permittivity) and h is the substrate thickness in cm.

The calculated parameters for different antennas designed at various resonant frequencies are given in

The simulated results of the antennas comprise of S parameter S11. Due to the ease of fabrication and availability of connectors, the antennas were fed using a rectangular microstrip line. The simulations were network analyzer. Fabricated antenna at frequency 4GHz and 10GHz are shown in Figure 3.1.2

In order to have a meaningful comparison between the simulated and measured results, the fabricated antennas are evaluated by extracting their S11. The simulated and measured data are over lapped in order to have better insight for comparison. These result for 2Ghz shown in figure 3.1.3.



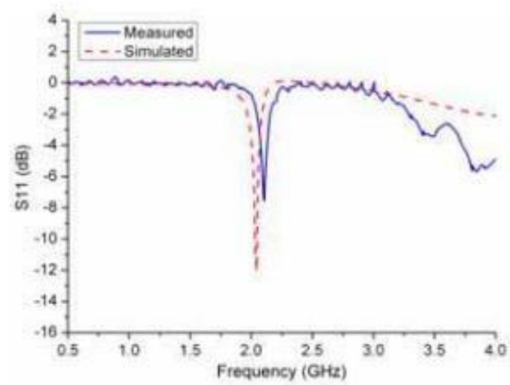


Figure 3.1.2: 2 GHz antenna results.

Figure 3.1.3: Fabricated antenna at (a) 4GHz (b) 10GHz.

The calculated parameters for different antennas designed at various resonant frequencies are givenin TABLE 3.1.

Table 3.1: FR-4 substrate parameters.

Substrate Parameter	**Value**
Dielectric constant: ε_r	4.5
Substrate thickness: h	1.5 mm
Loss tangent: δ	0.019
Conductor (copper) thickness: t	0.035 mm

Table 3.1.2: Antenna design parameters.

Frequency (GHz)	**Patch Radius, R (mm)**	**Feed point location, FR (mm)**	**Feed length, L (mm)**	**Feed Width, W (mm)**
2	20.224	15.1850	40.6	2.8
4	9.946	4.2869	20.08	2.4
6	6.540	2.5955	6.95	1.2
8	4.848	1.8641	5.15	1.2
10	3.838	1.789	4.1	1.2

3.2 Comparison between several CPW

In order to reduce size and avoid the complexity, major overlapped slots have been introduced in the proposed antenna design along with two strips above and below the main radiating patch. Compact ground plane length ratio to the overall length of the antenna is optimized to achieve 50 Ohm impedance matching by adjusting the microstrip width and gap between the microstrip and the sides of the ground plane. In Table 3, a comparison is made between different existing CPW designs found in literature and our proposed work.

Type	Total area (mm^2)	Bandwidth	Peak gain (dBi)
Dual-band	1020	2.3–2.5 and 2.9–15.0 GHz	2.5
Dual-band	900	1.86–1.97 and 3.0–12.0 GHz	3.0
Dual-band	1250	3.4–3.6 and 8–15 GHz	-------
Tri-band	1600	2.28–2.58, 3.38–3.66, and 5.07–5.86 GHz	3.3
Tri-band	839.5	2.33–2.76, 3.05–3.88, and 5.57–5.88 GHz	2.8
Dual-band	2700	2.26–2.57 and 4.81–6.56 GHz	3.2
Dual-band	1500	2386–2510 and 4878–6002 MHz	2.6
Tri-band	896	2.3–2.8, 3.1–4.0 and 4.6–5.3 GHz	3.0
Dual-band	1400	2.2–2.55 and 3.0–5.6 GHz	2.0

Table 3.2: Comparison between different existing CPW designs and our proposed work.

For proposed work (to moving 5G) bandwidth (20-30GHz) and the peak gain is less than -18 dBWhich are sufficient for beam steering issue.

3.3 Waveguide

Waveguide:

The evolution process of final antenna is shown in Figures 3.2(a)–4(d). Simulated refection coefficient results for all antenna design steps/types are depicted in Figure 5. The antenna design process is started from a coplanar waveguide fed printed antenna by attaching a rectangular patch with feed line that attains a very broad fractional impedance bandwidth of more than 100% (1.1 GHz–3.9) GHz for $S_{11} < -10$ dB threshold without having second resonant band. However, our design goal is to make a dual-band antenna in which each band tuned/modified comparatively independently without significantly affecting the other band as per our design needs. The 2nd design goal is to increase the gain of the antenna as CPW-fed printed antennas are generally omnidirectional antennas. In order to achieve these design goals, Antenna 1 is modified by adding an additional rectangular strip that creates a second resonance around 3.4 GHz as shown in Figure 3.2(b). Antenna 3 is created by adding another top strip and etching overlapped slots in first rectangular patch that shows first resonance at

2.4 GHz with impedance bandwidth from 1.0 GHz to 2.7 GHz and a second resonance at 3.4 GHz with impedance bandwidth from around 3.1 GHz to 3.7 GHz. Finally, Antenna 4 (proposed) is simulated and fabricated with imbedded rounded corners technique for improved performance in terms of refection coefficient and gain. Tis design attains dual bands with a simulated result of around 80% fractional bandwidth (1.1 GHz–2.8 GHz) in the first band and around 23% fractional impedance bandwidth (3.0 GHz–3.75 GHz) in the second resonance band. Tis is worth mentioning that S_{11} has shown better notched frequency characteristic between the two bands. On the other hand, it is noted that introducing rounded corners has a very low effect on the resonant frequencies, but it has effectively improved the fractional impedance bandwidth and the gain of the final antenna design. Detailed parametric studies have been carried out including all the major lengths, widths, feed lines, and positions of rectangular strips to achieve higher gain of the proposed design. [8]

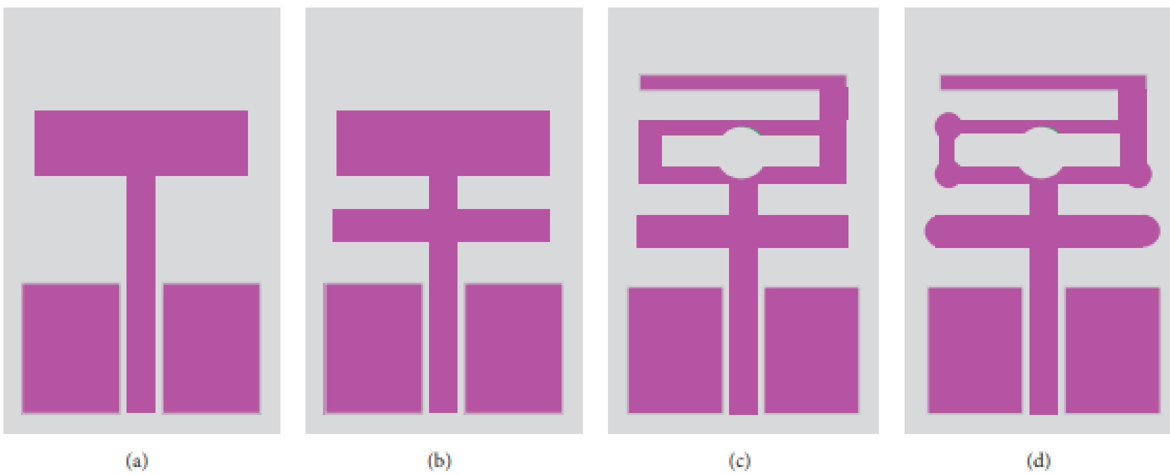


Figure 3.2: Evolution process of antenna: (a) Antenna 1, (b) Antenna 2, (c) Antenna 3, and (d) final proposed antenna.

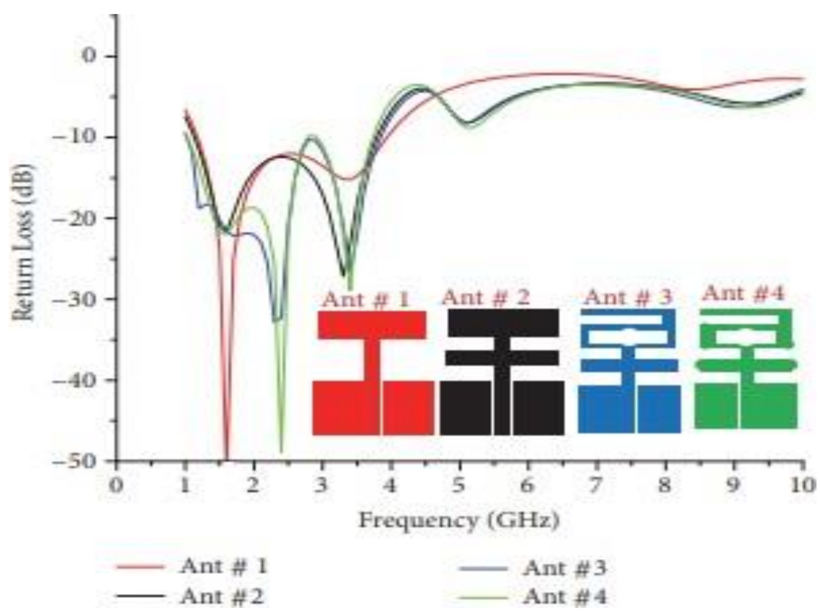


Figure 3.3: Simulated reflection coefficients of the four antennas.

3.4 Waveguide port :

Waveguide ports represent a special kind of boundary condition of the calculation domain, enabling the stimulation as well as the absorption of energy. This kind of port simulates an infinitely long waveguide connected to the structure. The waveguide modes travel out of the structure toward the boundary planes thus leaving the computation domain with very low levels of reflections.

Very low reflections can be achieved when the waveguide mode patterns in the port match perfectly with the mode patterns from the waveguides inside the structure. CST MICROWAVE STUDIO uses a 2D eigenmode solver to calculate the waveguide port modes. This procedure can provide very low levels of reflection below -10dB in some cases.

3.5 Coplanar waveguide (CPW) :

The coplanar line is a frequently used transmission line for high frequency devices. Depending on whether the substrate is backed by a metallic shielding or not, the waveguide is either called ungrounded coplanar line or grounded coplanar line. The size of the port is a very important consideration. On one hand, the port needs to be large enough to enclose the significant part of the coplanar line field. On the other hand, the port size should not be unnecessarily large because this may cause higher order waveguide modes to propagate in the port. [8]

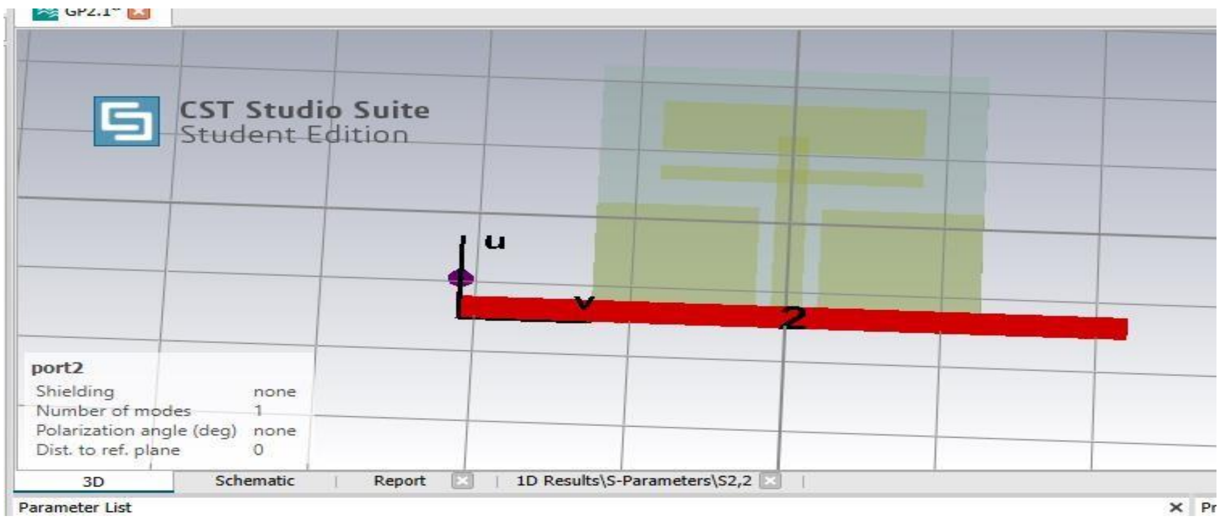


Figure 3.4: our waveguide port of the proposed antenna

4 DESIGNING SPACEIFICATIONS

4.1 Substrate waveguide:

The design of circularly polarized substrate integrated waveguide (SIW) antenna in X band using the FR4 and RT Rogers is presented in this report. The substrate integrated waveguides represent the family of substrate integrated circuits which is planar in nature and used for the transmission of electromagnetic energy. Methods/Statistical Analysis: In this paper, the design techniques for substrate integrated waveguide using slots with the integration of micro-strip with the substrates FR4 and RT Rogers are presented, which emphasize the broad perspective of the substrate integrated waveguide in circular polarization. Findings: The design has simulated in HFSS Software. From the simulation results, it is observed that gain has increased in SIW structure with slots for circular polarization as compared to SIW structure without slots also by comparing the substrate structure with RT Rogers shows good gain than the structure with FR4. [10]

The figure 4.1 shows the simulated substrate with FR4 with Dimensions using CST studio suite .

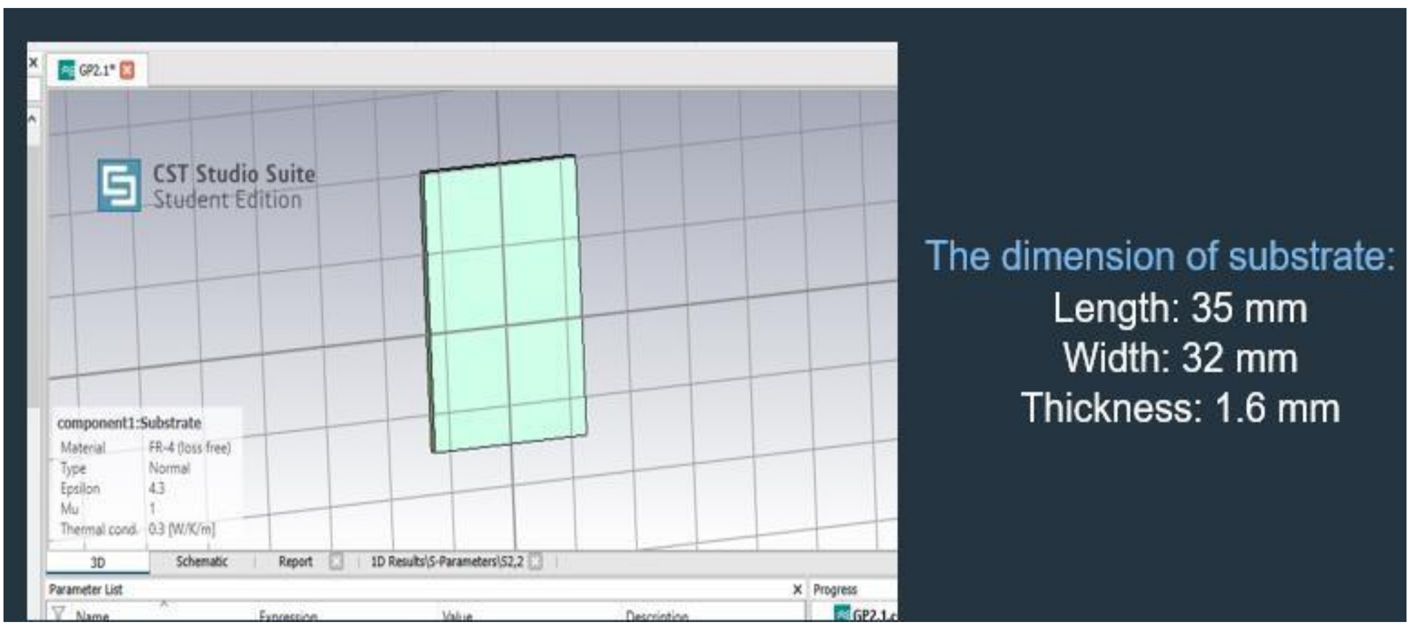


Figure 4.1: the substrate FR4 (loss free).

- The frequency for design is f_{min} around 2.1 GHz and f_{max} at 3.6 GHz) for (4G frequency)
- (material for substrate FR4 (loss free) ε_r = 4.3)

4.2 Ground planes and feed line:

The figure 4.2 shows the simulated substrate (FR4) and Ground planes and feedline (copper) with Dimensions.

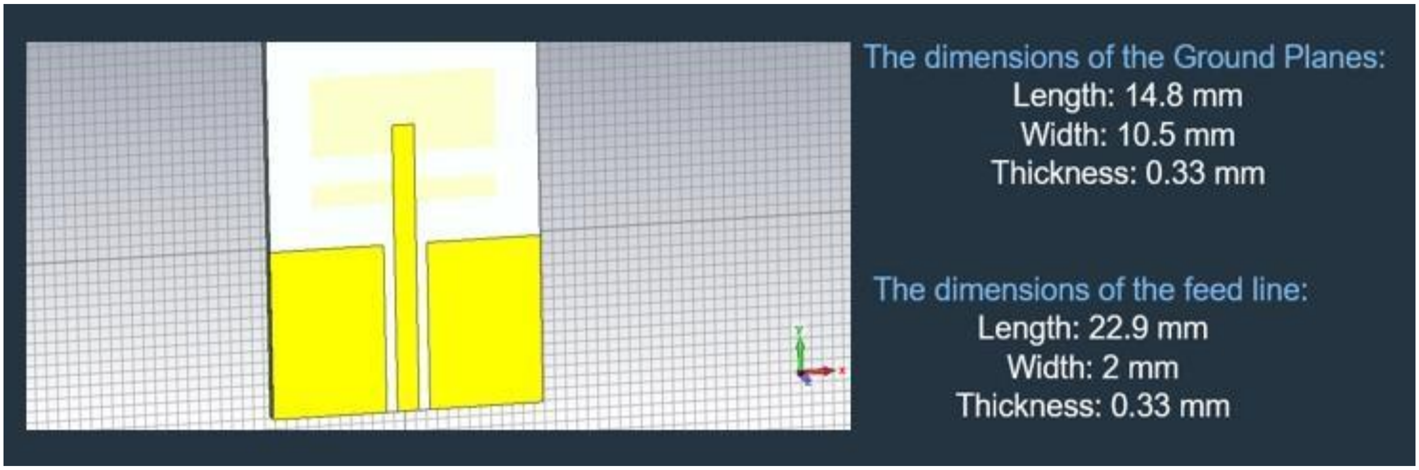


Figure 4.2: Ground planes and feedline (copper).

4.3 Radiation part:

The figure 4.3 shows the simulated substrate (FR4) and Radiation parts (copper) with Dimensions. Which the specific designs are used for center slot and circulated corner that make the result of s11 change for bandwidth and make it better working.

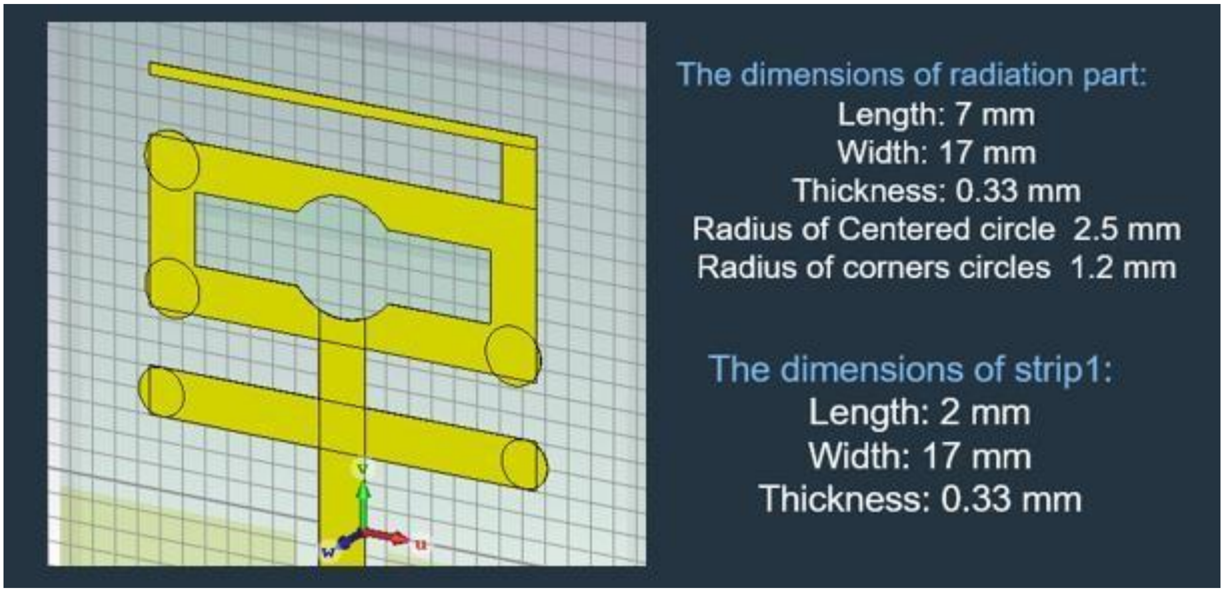


Figure 4.3: Radiation part (copper).

4.4 Wave-guide port:

The figure 4.4 shows the wave-guide port with dimensions.

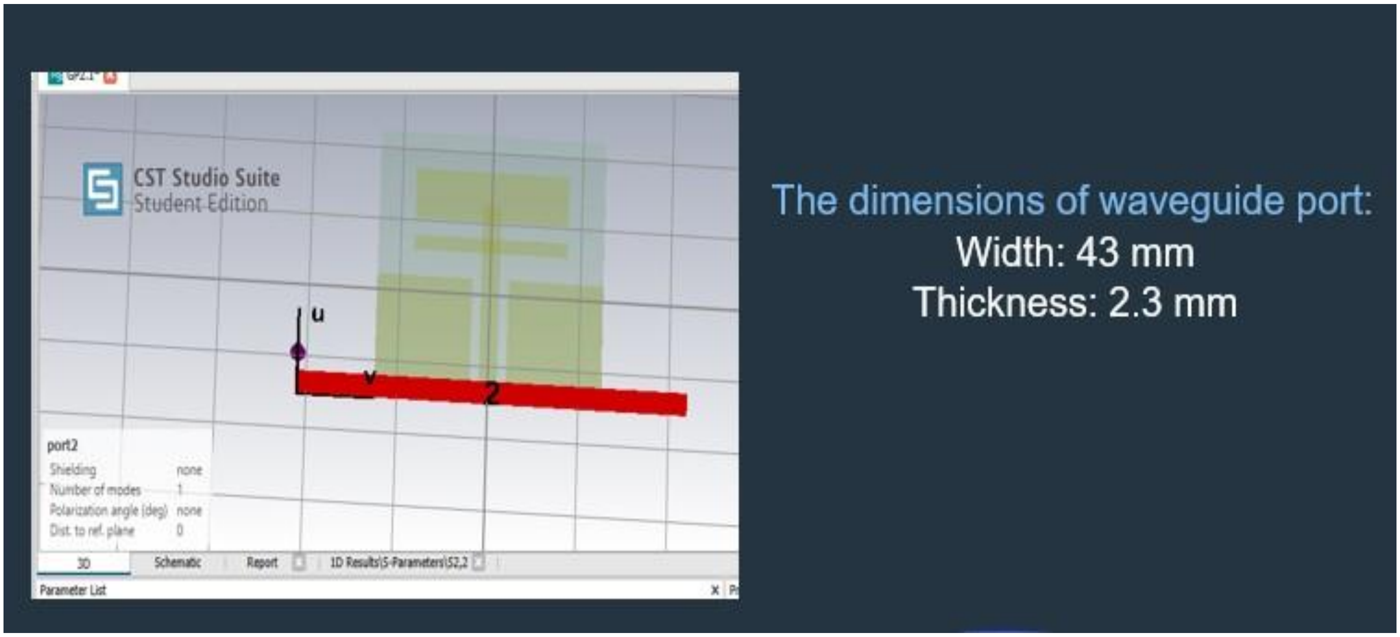


Figure 4.4: the wave-guide port.

We complete designing the component of proposed antenna with CST studio suite. Moreover, the figure 4.5 shows all component.

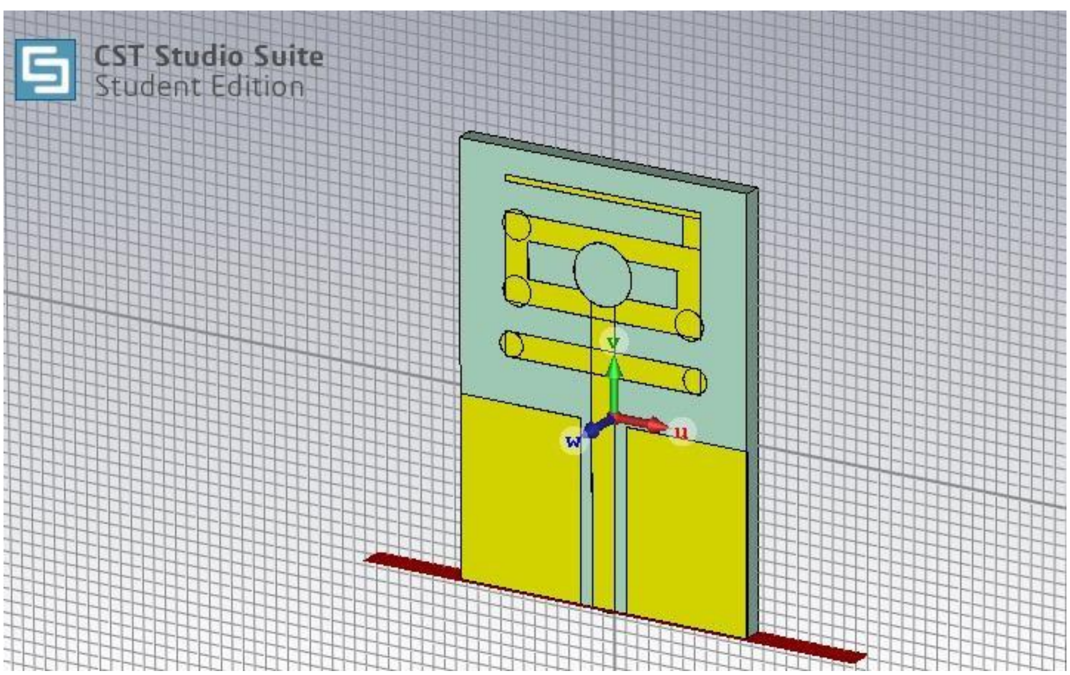


Figure 4.5: all component.

5 RESULTS

5.1 Results of our halfway design

For moving to 5G we have to change on design specification such as size and thickness to achieve good performance in terms of gain and efficiency, Our designing was separated for two section: first shape of design for first semester that is work in 4G frequencies and to moving to 5G frequencies such as 28 GHz, we try to change material and change the thickness and size. Trying with Roger RT5880 (lossy) material with reducing thickness to 0.256 showing below.

Figure 5.1: shows shape design with material Rogers (epsilon =2.2.)

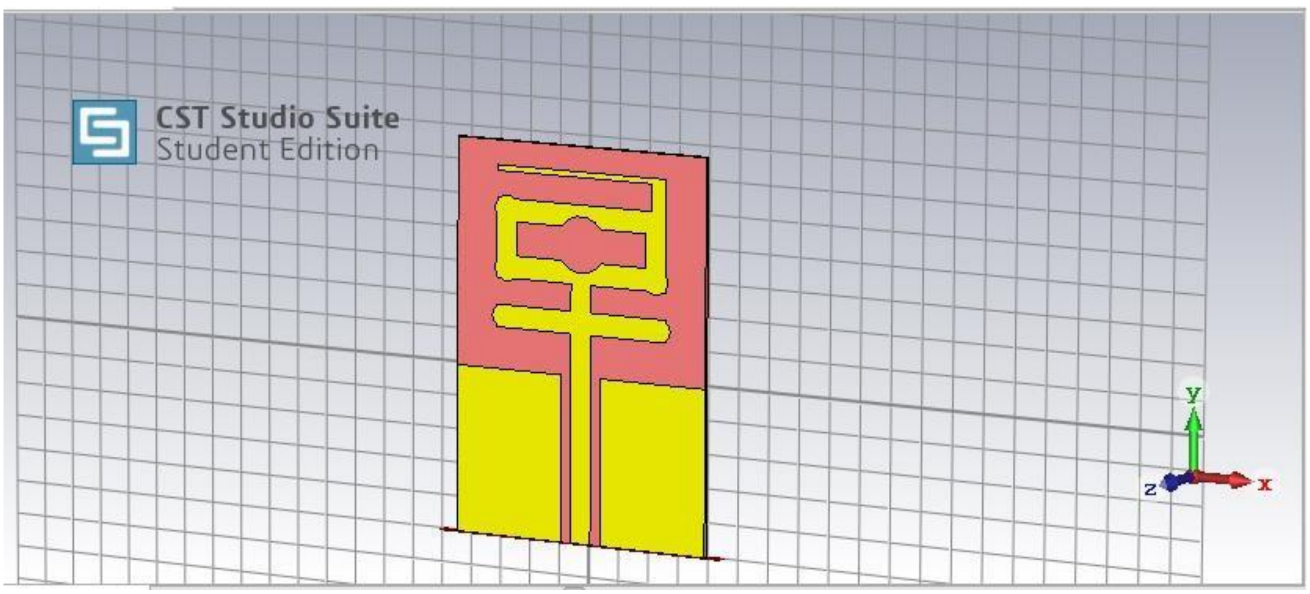


Figure 5.1: halfway design.

Simulated reflection coefficient of the above antenna from 20 GHz to 70GHz.

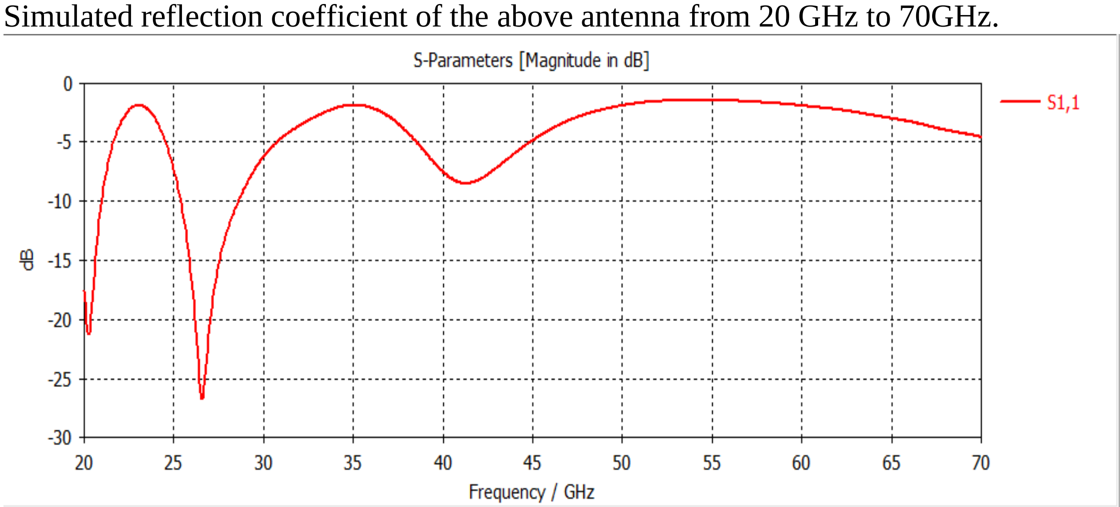


Figure 5.2: the S1.1 of halfway design

5.1.1 The Result of S-parameter:

S-parameters describe the input-output relationship between ports (or terminals) in an electrical system. For instance, if we have 2 ports (intelligently called Port 1 and Port 2), then S12 represents the power transferred from Port 2 to Port 1. S21 represents the power transferred from Port 1 to Port 2. In general, SNM represents the power transferred from Port M to Port N in a multi-port network. A port can be loosely defined as any place where we can deliver voltage and current. So, if we have a communication system with two radios (radio 1 and radio 2), then the radio terminals (which deliver power to the two antennas) would be the two ports. S11 then would be the reflected power radio 1 is trying to deliver to antenna 1. S22 would be the reflected power radio 2 is attempting to deliver to antenna 2. And S12 is the power from radio 2 that is delivered through antenna 1 to radio 1. Note that in general S-parameters are a function of frequency (i.e. vary with frequency). We are mainly concerned with S11 parameter as it is the most commonly quoted parameter in regards to antennas.S11 represents how much power is reflected from the antenna, and hence is known as the reflection coefficient. If S11=0 dB, then all the power is reflected from the antenna and nothing is radiated. If S11=-10 dB, this implies that if 3 dB of power is delivered to the antenna, -7 dB is the reflected power. The remainder of the power was "accepted by" or delivered to the antenna. This accepted power is either radiated or absorbed as losses within the antenna. Since antennas are typically designed to be low loss, ideally the majority of the power delivered to the antenna is radiated.

5.1.2 The Radiation Pattern:

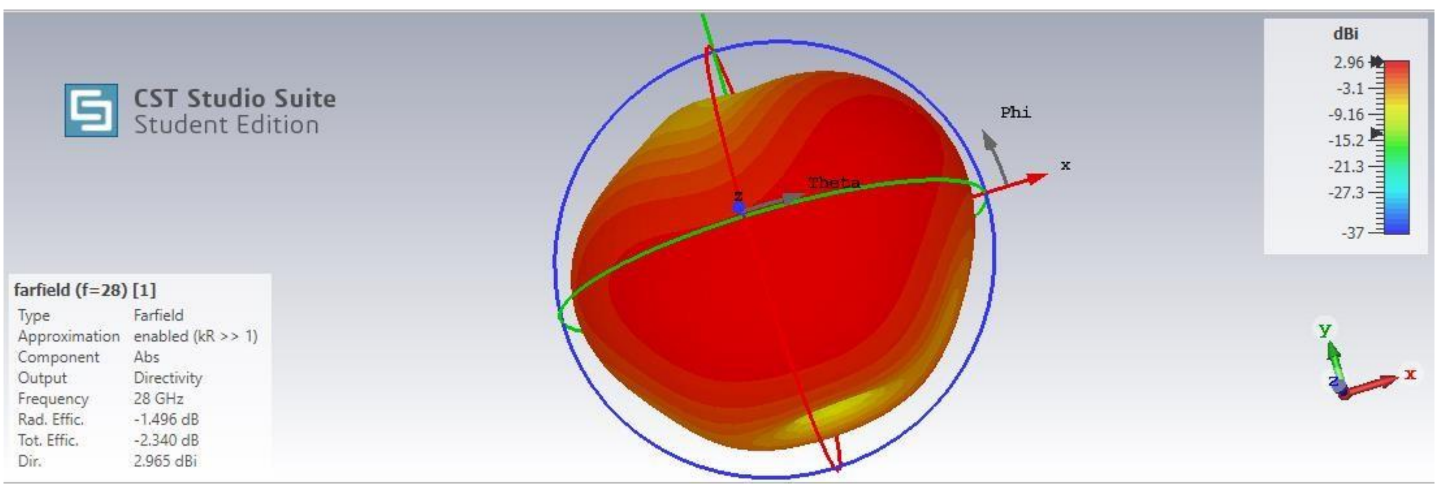


Figure 5.2.1: the result of Radiation pattern for halfway design.

A radiation pattern in figure 5.2.1 defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. This power variation as a function of the arrival angle is observed in the antenna's far field .Standard spherical coordinates are used, where polar angle theta for plots in spherical coordinates is the angle measured off the z-axis, and phi, the azimuth angle of spherical coordinates in antenna patterns is the angle measured counterclockwise off the x-axis

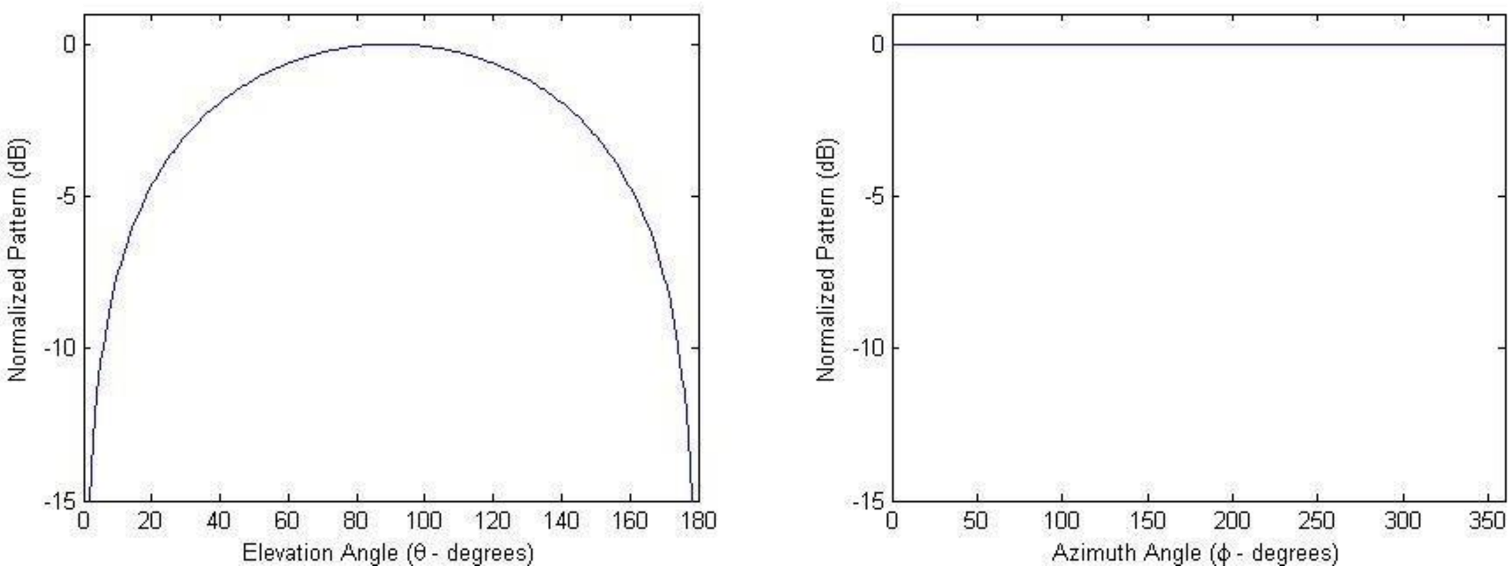


Figure 5.2.2: Two-dimensional Radiation Patterns.

5.2 Results of our final proposed antenna design:

Implemented using low cost FR-4 substrates

Figure 5.3 shows the Final shape of design after many trials we back to material FR-4

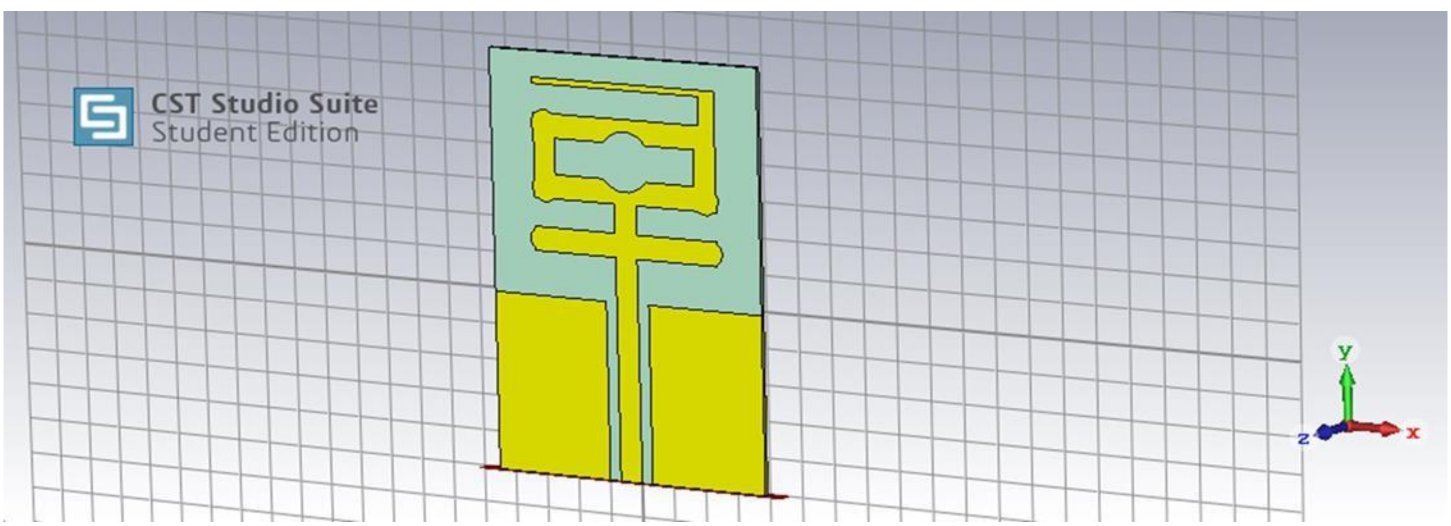


Figure 5.3: Final design.

Figure 5.4 shows the simulated reflection coefficient of the above antenna from 20GHz to 30 GHz.

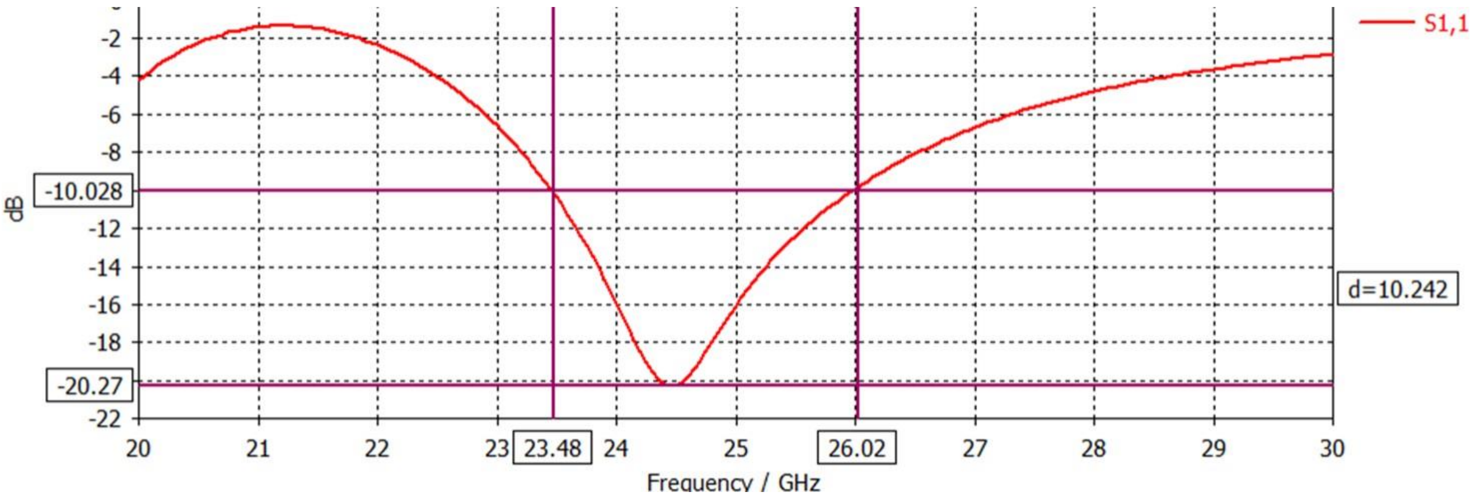


Figure 5.4: result of S-Parameter S1.1

From Fig. 5.4, it is apparent that the simulated and measured results for the resonant frequency and impedance bandwidth.

Bandwidth: working at (23 GHz-26 GHz) where S1.1 below -10dB.

The above figure implies that the antenna radiates best at 24.5GHz, where S11=-20dB. Further, at

2.75 GHz the antenna will radiate virtually nothing, as S11 is close to 0 dB (so all the power is reflected).

The S-parameter matrix can be used to determine reflection coefficients and transmission gains from both sides of a two port network. This concept can further be used to determine s-parameters of a multiport network.

Figure 5.5 shows the different S parameters and what are they stands for.

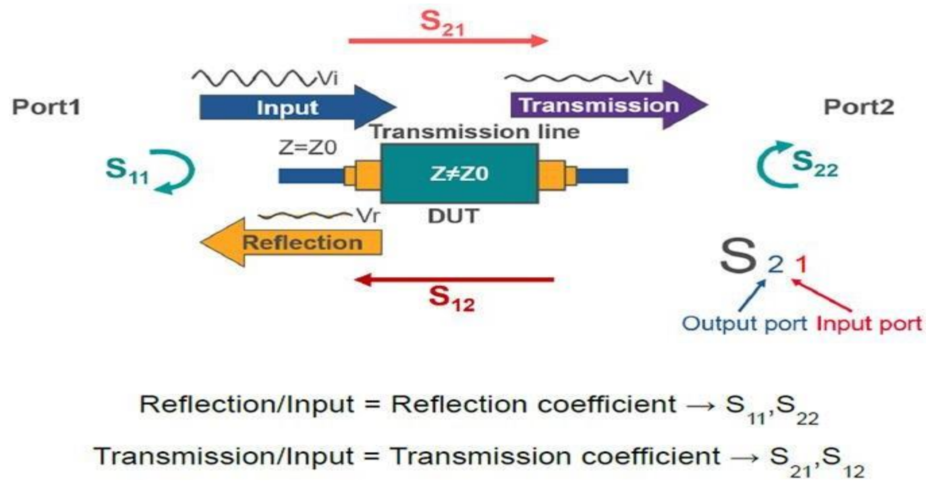


Figure 5.5: different S parameters and its function.

Antenna Performance (far field at 28 GHz) with 3dBi.

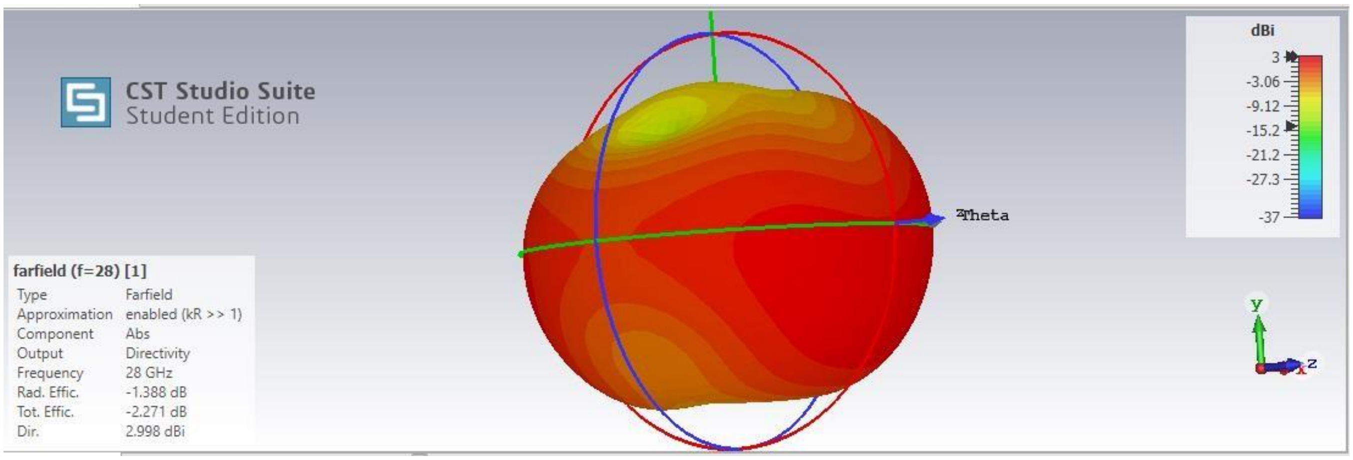


Figure 5.6: Radiation Pattern with intensity at (f=28GHz) of far fields with ~ (3dBi).

6 CONCLUSIONS

- In this paper, a new air filled slot-loop phased array antenna aiming for 5G mobile communications is presented. The antenna is designed on a low-cost substrate (FR-4) to operate around 28 GHz.
- Ten elements of slot-loop antenna elements have been used to form a uniform linear array on the top region of the cellular handset PCB.
- The proposed antenna has good performance in terms of S-parameter.
- Top strip and bottom strips effectively control resonance bands.
- The proposed design is very small in size which makes it a suitable contender for different portable and handheld IOT applications. [8]
- The main advantages of the 5G are a greater speed in the transmissions,a lower latency and therefore greater capacity of remote execution, a greater number of connected devices and the possibility of implementingvirtual networks.
- 5G support a massive number of static and mobile IoT devices, which have a diverse range of speed, bandwidth and quality of service requirements.
- In order to have the antenna working on 5G bands, its size should be significantly small.
- The range of 5G depends on many factors. A key factor is the frequencybeing used.
- The range of mmWave signals tend to be only a couple of hundred meters whilst low band signals can, in the right circumstances, have a theoretical range of a couple of hundred kilometers.
- 5G in the 24 GHz range or above use higher frequencies than 4G, and asa result, some 5G signals are not capable of traveling large distances (over a few hundred meters), unlike 4G or lower frequency 5G signals (sub 6 GHz).
- After many trials, we conclude that FR-4 material with εr=4.4 is the choice for our design.

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